PNNL-SA-38168

A Vintage Based Approach for Assessing Geologic Sequestration Options for U.S. Power Plants

Robert T. Dahowski, Senior Research Engineer
James J. Dooley, Staff Scientist

Presented at:
The Second Annual Conference on Carbon Sequestration
Alexandria, Virginia
May 7, 2003

Summary Points

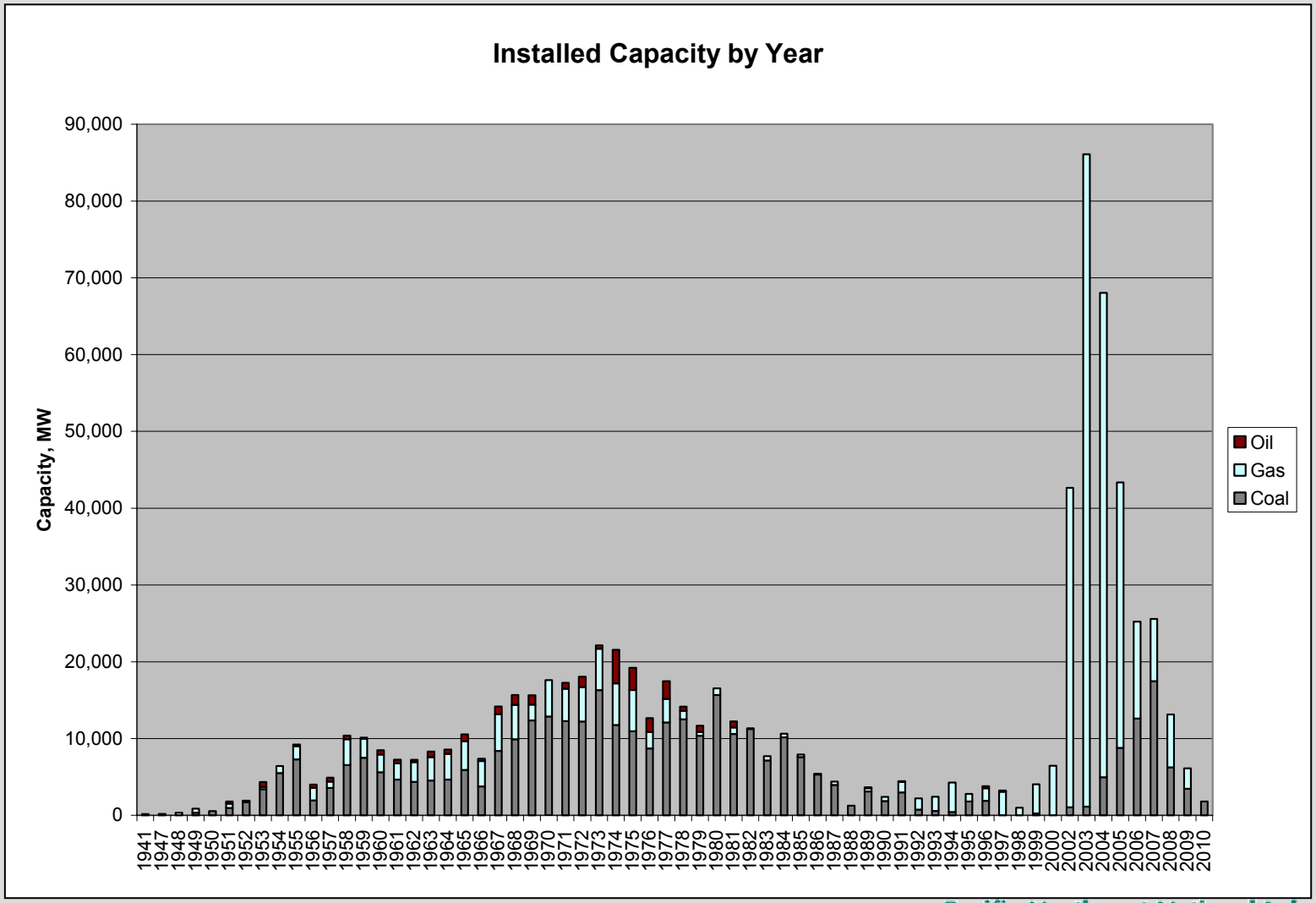
- U.S. “electric power sector” is not a homogenous / monolithic entity
- Proposals to retire the oldest power plants and replace them with “sequestration ready units” must take account of location and this heterogeneity
- In general the oldest operational plants are relatively small coal fired units in the Southeast and Ohio River Valley and the majority of these plants’ sites appear well situated for sequestration
- Majority of U.S. power plant CO_2 emissions can be disposed of without the need for extensive pipeline infrastructure
- Deep saline formations and coal beds are overwhelmingly the reservoirs of choice for existing power plants’ CO_2

U.S. Electric Power Sector

- Electric power sector responsible for 38% of total U.S. CO_2 emissions
- 1346 large fossil-fired generating units (≥ 100 MW)
- Vintages range from 1940's through today
- 448 GW total combined capacity
- 2.3 billion tons of CO_2 emitted annually
- 455 new projects (up to 311 GW) could potentially come online by 2010

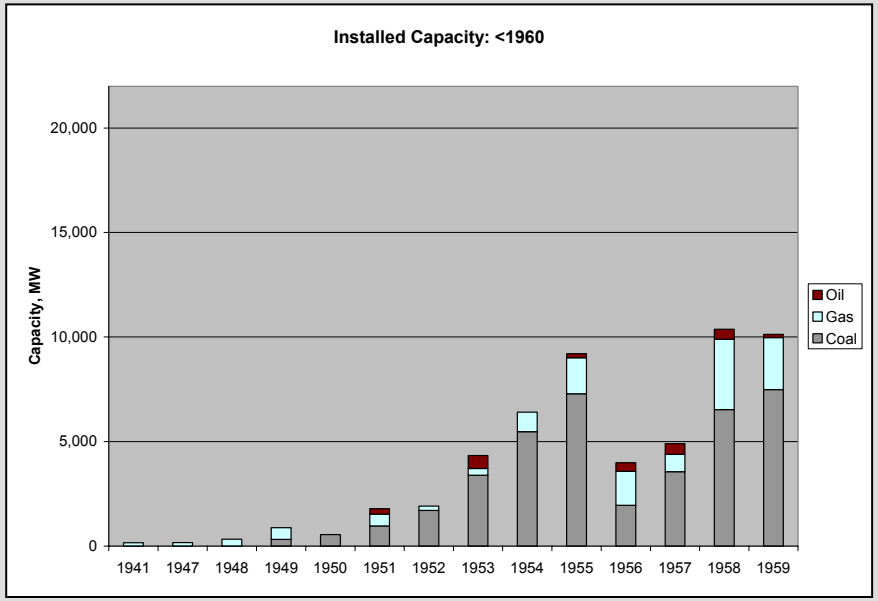
- These existing and planned power plants are valuable assets for their owners and the nation
- Whether they remain assets or become liabilities -- if and when -- we enter into a world of carbon constraints hinges upon whether there are options for controlling their emissions

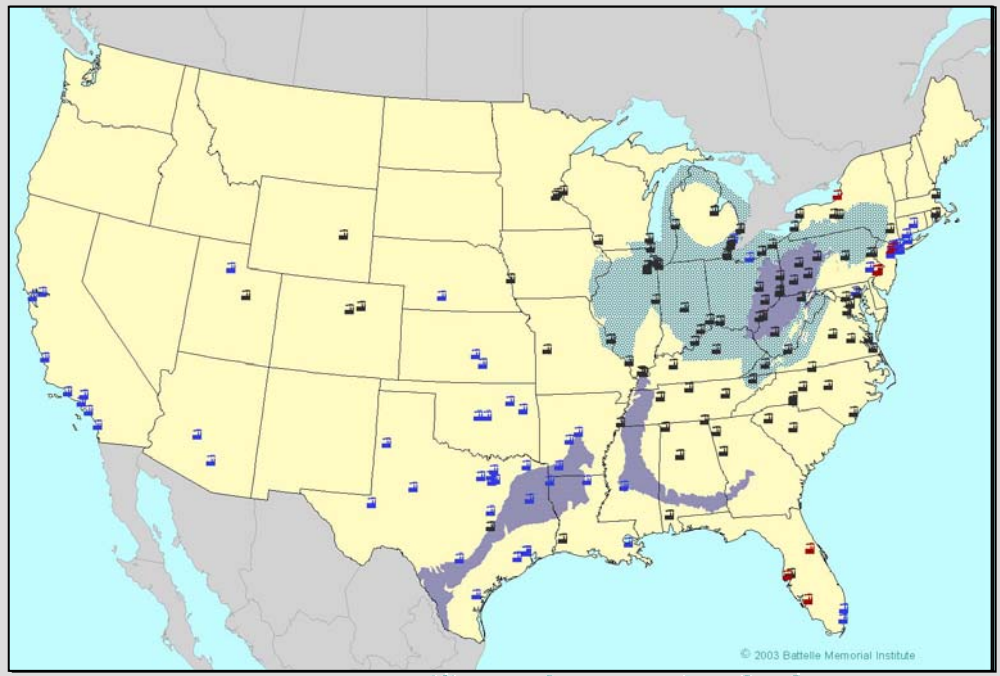
Large Operating or Planned U.S. Fossil-Fired Generation Capacity by Year Installed



Existing Units: On-Line Pre-1960

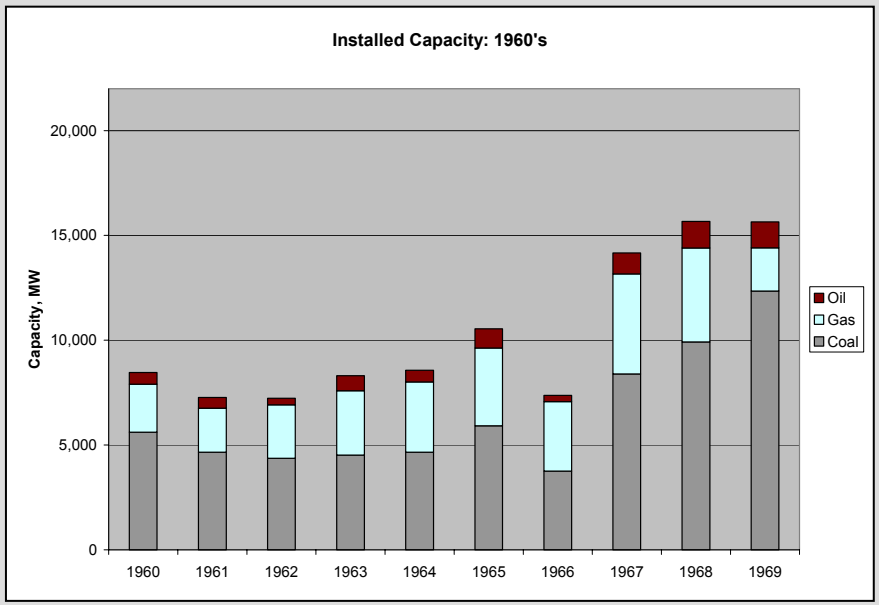
- **324 units (223 coal, 86 gas, 15 oil)**
  - 55,120 MW capacity / 258 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Mt. Simon, Oriskany
    - By cost: Gulf Coastal Plain, N. Appalachian Basin

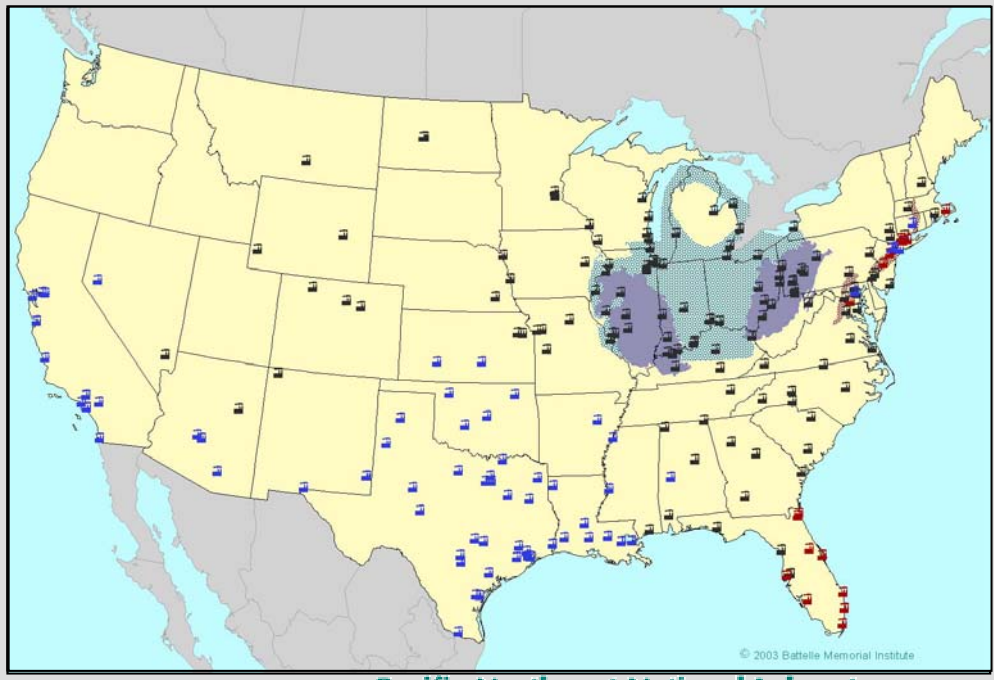




Existing Units: On-Line 1960's

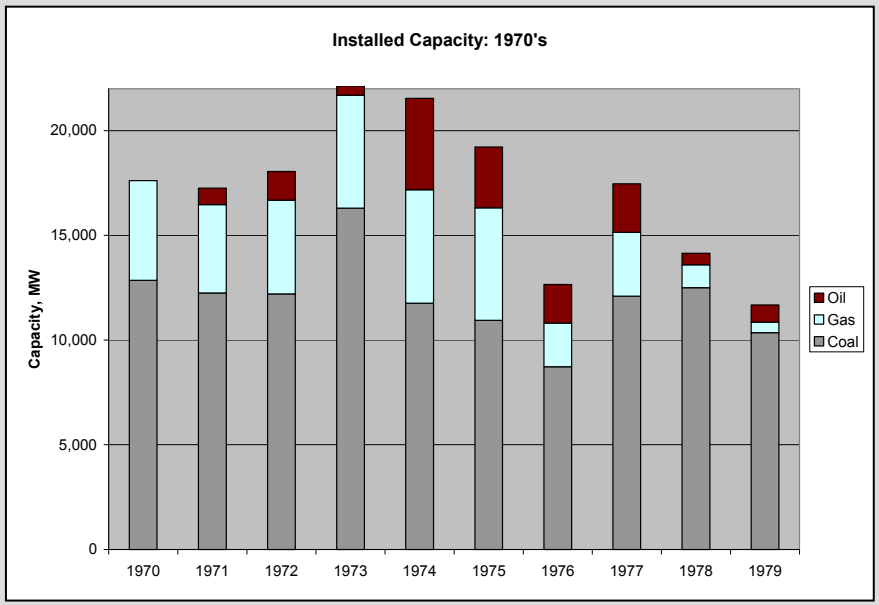
- **334 units (200 coal, 108 gas, 26 oil)**
  - 103,237 MW capacity / 464 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Mt. Simon, Newark Supergroup (basalt)
    - By cost: N. Appalachian Basin, Illinois Basin

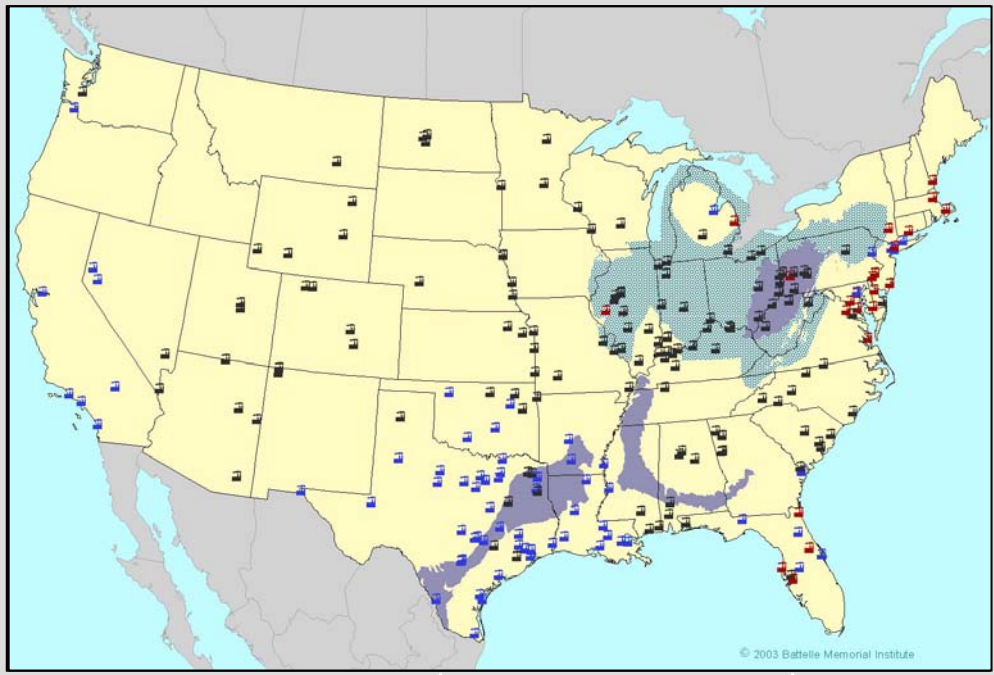




Existing Units: On-Line 1970's

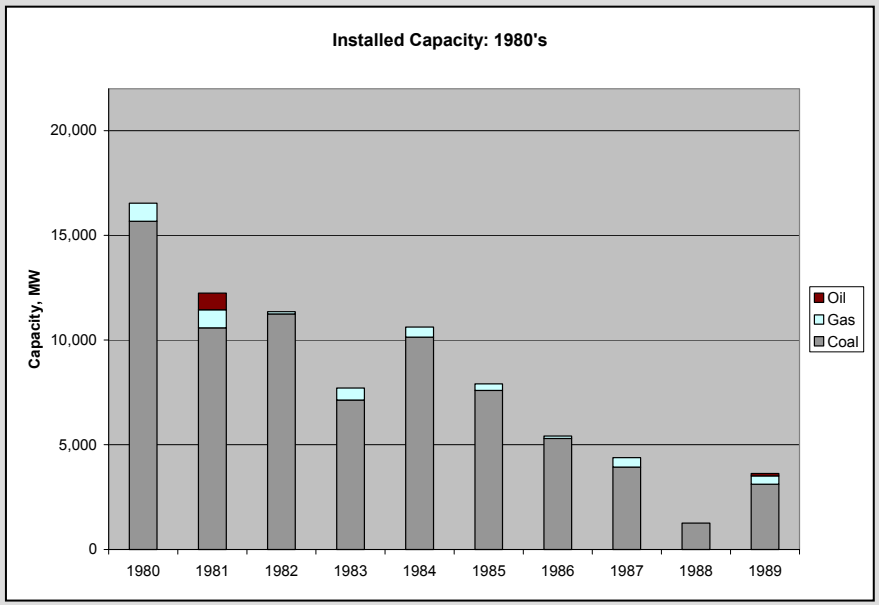
- **339 units (213 coal, 95 gas, 31 oil)**
  - 171,755 MW capacity / 897 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Mt. Simon, Oriskany
    - By cost: N. Appalachian Basin, Gulf Coastal Plain

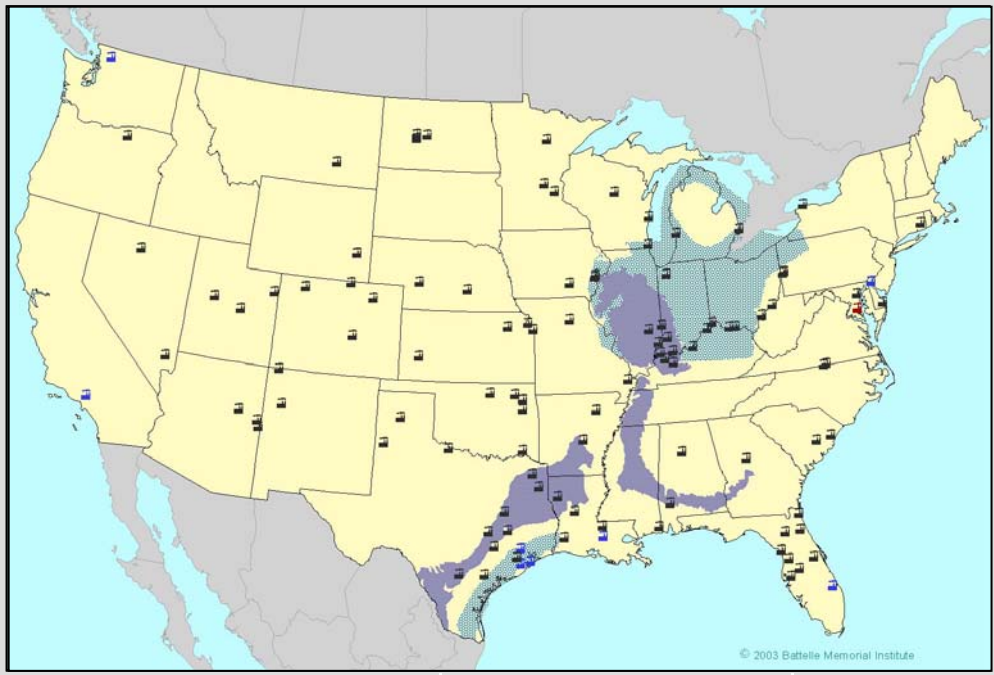




Existing Units: On-Line 1980's

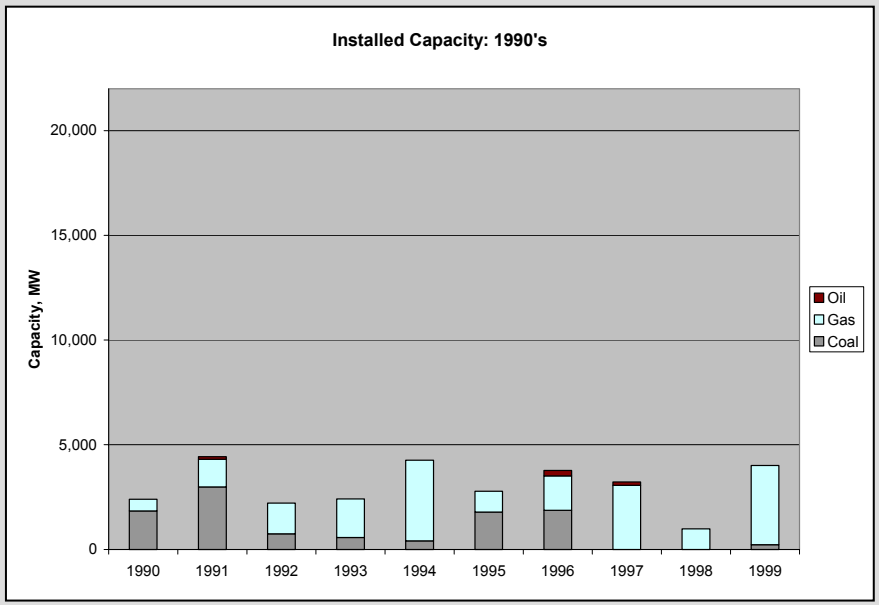
- **161 units (135 coal, 23 gas, 3 oil)**
  - 81,047 MW capacity / 581 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Mt. Simon, Frio Formation
    - By cost: Gulf Coastal Plain, Illinois Basin

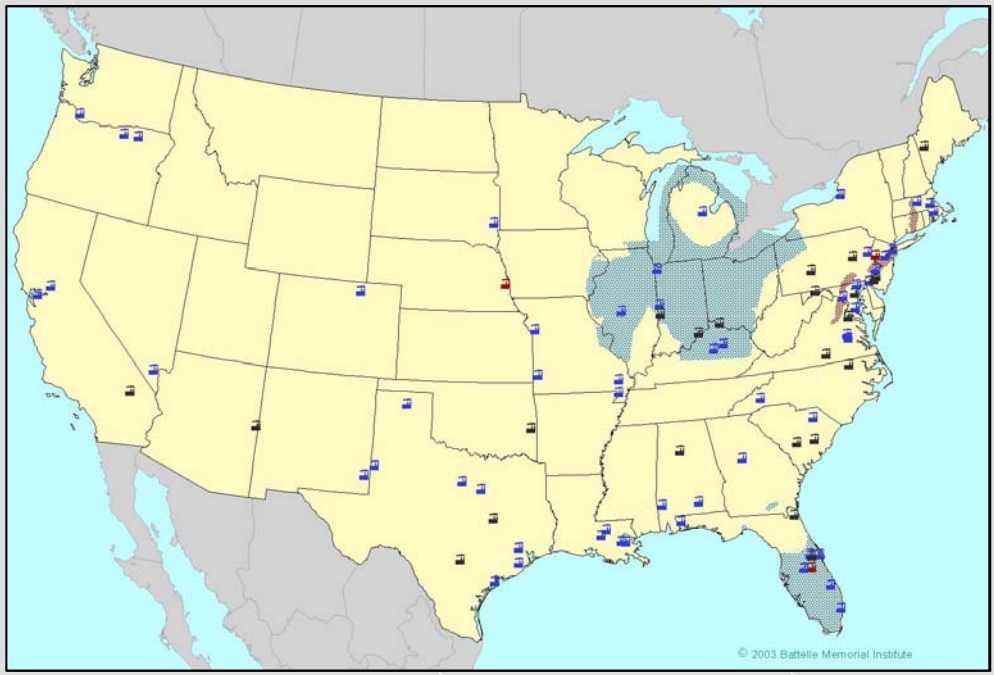




Existing Units: On-Line 1990's

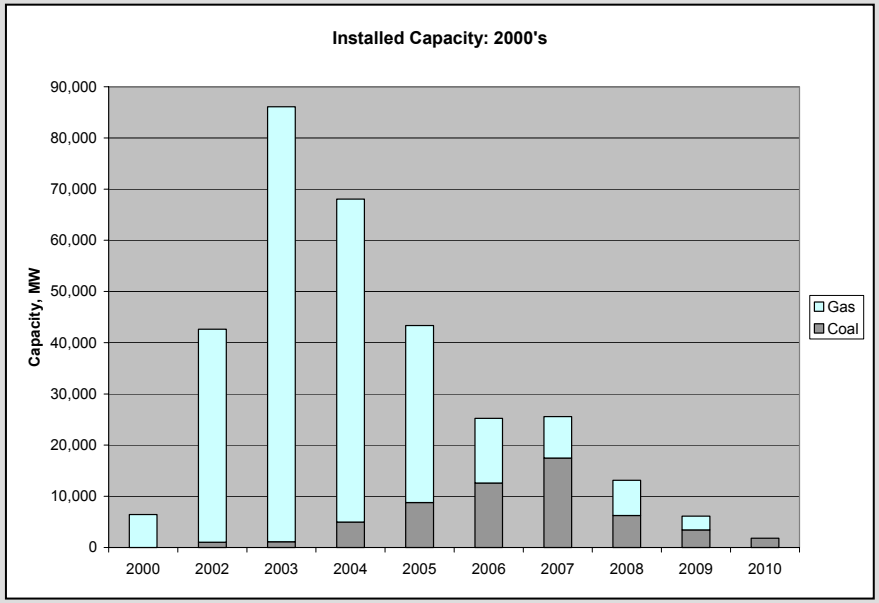
- **152 units (30 coal, 118 gas, 4 oil)**
  - 30,507 MW capacity / 115 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Cedar Keys/Lawson, Newark Supergroup
    - By cost: Cedar Keys/Lawson, Mt. Simon

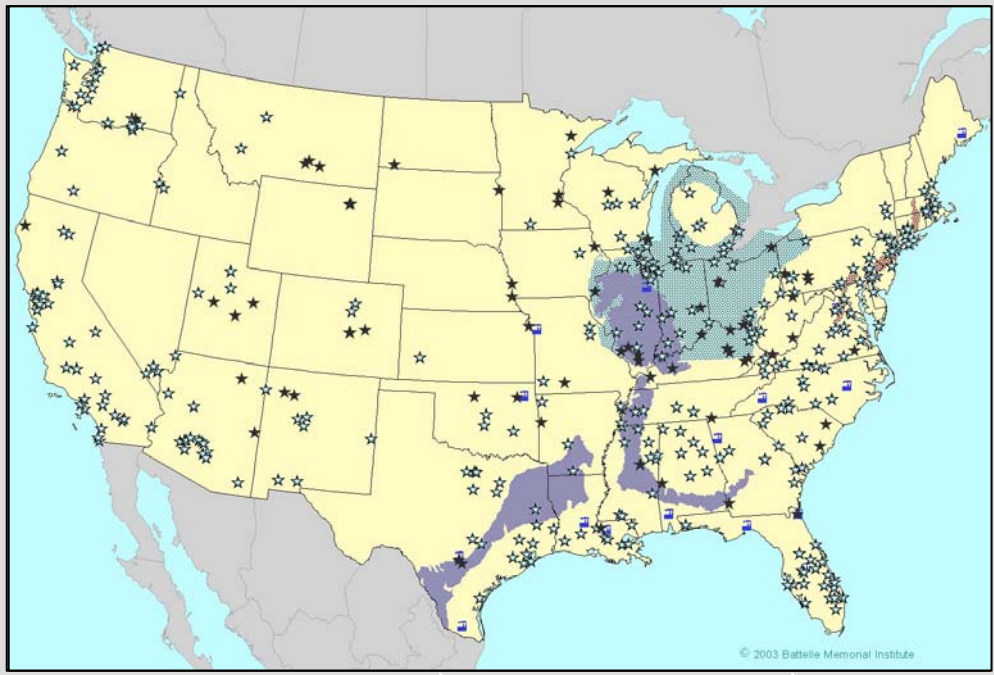




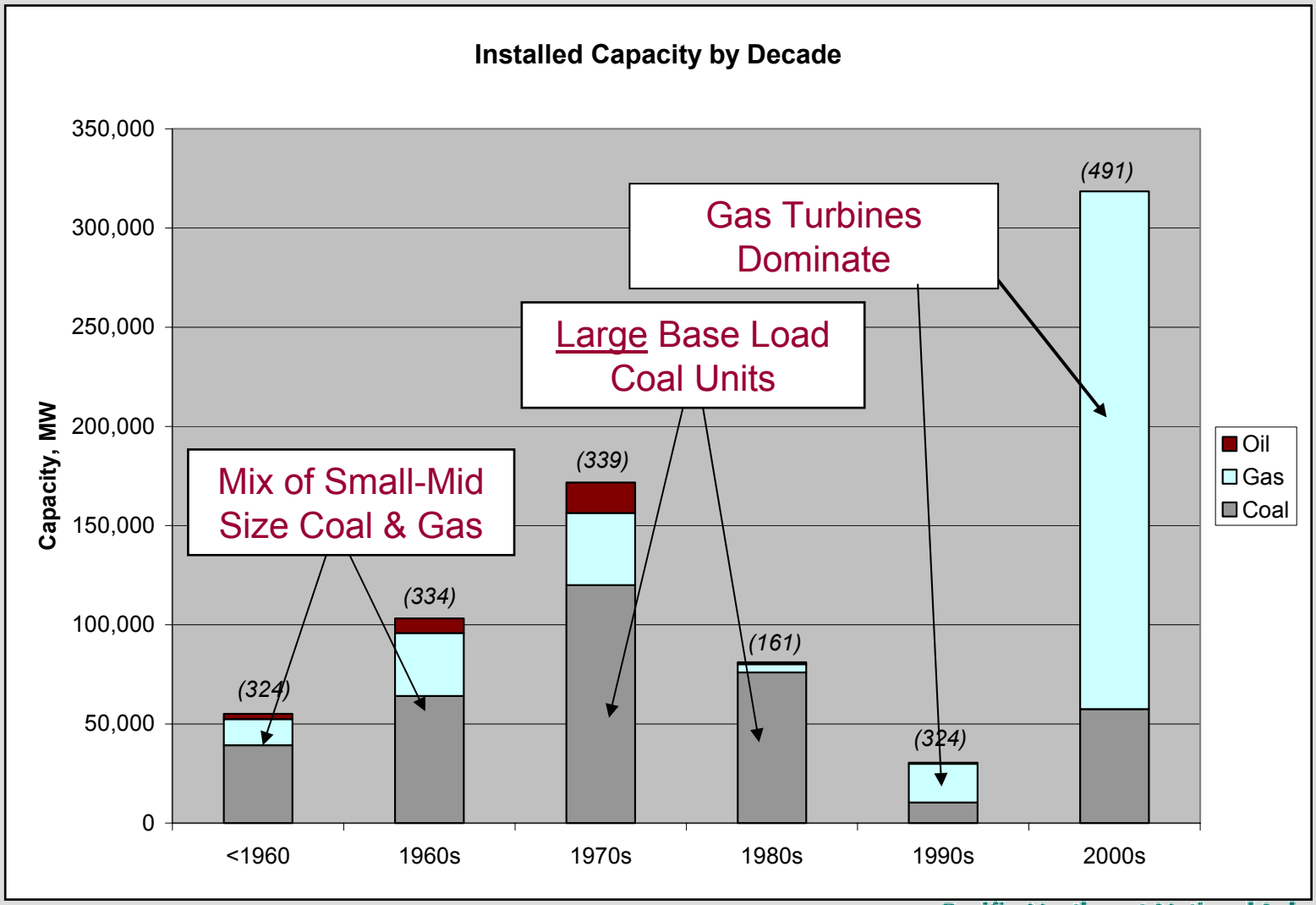
Units On-Line 2000's (Existing & Planned)

- **491 units (73 coal, 418 gas, 0 oil)**
  - 760,094 MW capacity / 3,293 million tons CO_2/yr
  - Key sequestration reservoirs:
    - By proximity: Mt. Simon, Newark Supergroup
    - By cost: Illinois Basin, Gulf Coastal Plain





Large Operating or Planned U.S. Fossil-Fired Generation Capacity by Decade Installed



Summary – Characteristics & Sequestration Cost

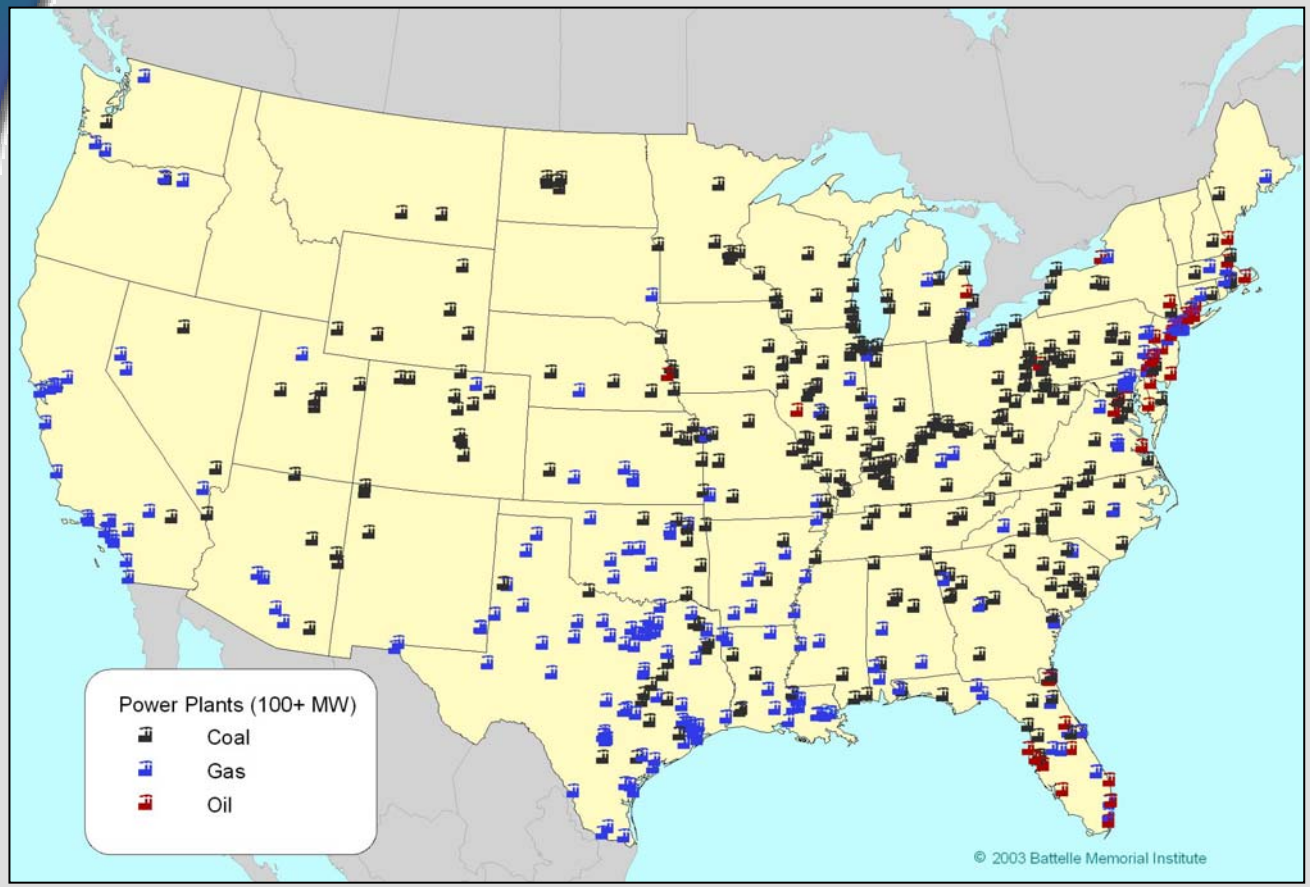
Vintage / Class	Predominant Power Gen Type	Nearest Reservoir Type	Predominant Lowest Cost* Reservoir Type	Overall Cost (predominant characteristic)
<1960	Small coal (170 MW average) units with low capacity factors	Deep Saline Formations	Coal Seams / ECBM	High Cost
1960's	Midsize coal (300 MW average) units with moderate capacity factors	Deep Saline Formations (Sedimentary & Basalt)	Deep Saline Formations (Sedimentary & Basalt)	Moderate to High Cost
1970's	Large coal units; high capacity factors	Deep Saline Formations	Coal Seams / ECBM	Low Cost
1980s	Large coal units; high capacity factors	Deep Saline Formations	Deep Saline Formations (Sedimentary & Basalt)	Low Cost
1990s	Small peaking gas units	Deep Saline Formations (Sedimentary & Basalt)	Deep Saline Formations	High Cost
2000s	Gas units	Deep Saline Formations (Sedimentary & Basalt)	Deep Saline Formations (Sedimentary & Basalt)	High Cost

** Within 50 mile radius of each unit*

Conclusions

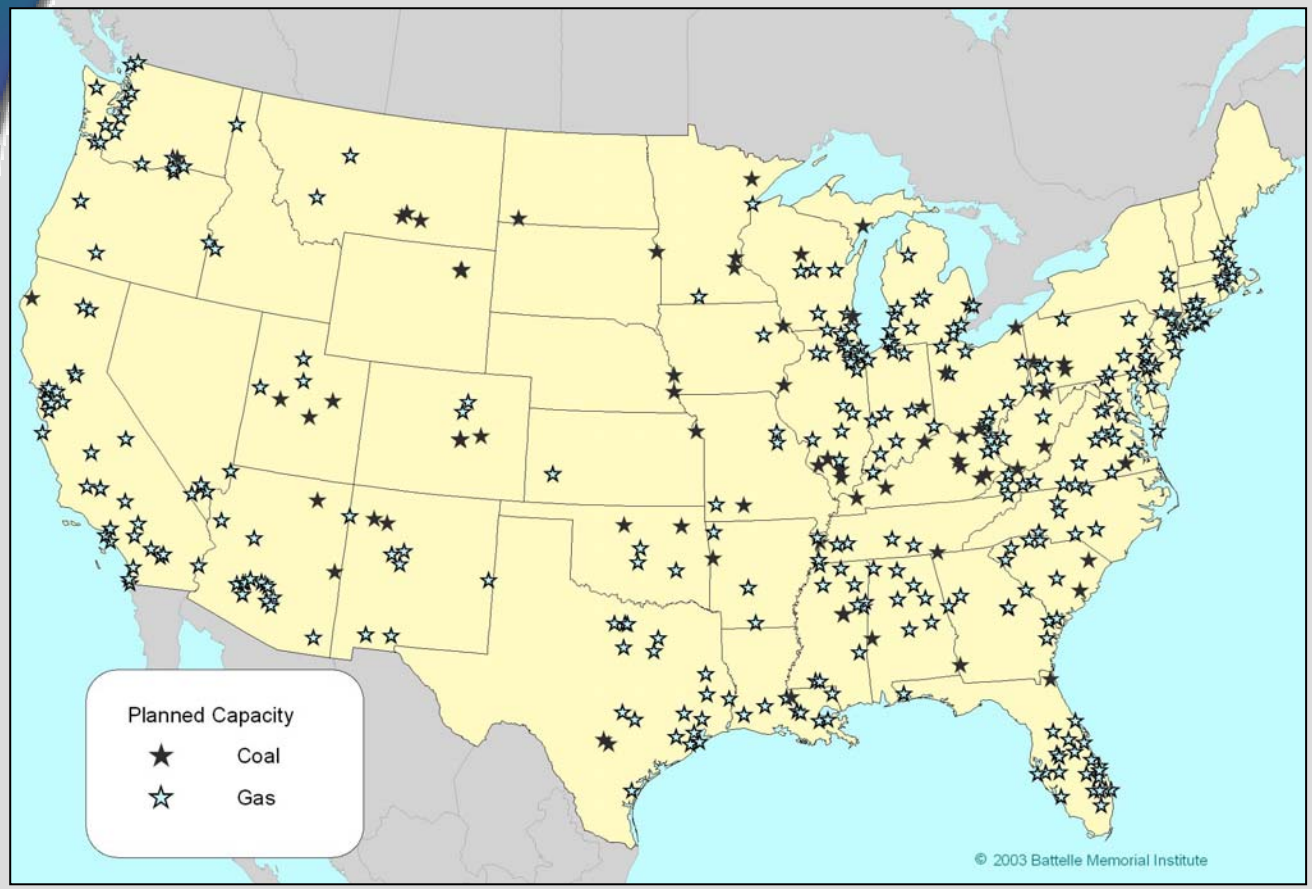
- Existing U.S. electric generating capacity is composed of a heterogeneous set of individual power generating units
- The oldest and newest existing plants have relatively higher cost of CO_2 capture and sequestration due to fuel type (natural gas) and low capacity factors
- Large base load power units built in the 1970s and 1980s have relatively lower costs when compared to other existing units
- Potential for a significant amount of new capacity to come on-line this decade, mostly conventional technology – contributing significant CO_2 emissions
- Coal seams offer a key sequestration reservoir if a positive price for CO_2 can be maintained; otherwise deep saline formations become CO_2 reservoir of choice for all vintage classes

Battelle CO_2-GIS:
CO_2 Sources: U.S. Fossil-Fired Generation



- 1346 Units at 588 locations (≥ 100 MW)
- 801 Coal (309,762 MW)
- 466 Natural Gas (111,452 MW)
- 79 Oil (26,898 MW)
- 2.3 billion tons CO_2 per year

Battelle CO_2-GIS:
Announced Fossil Power Projects



- 455 projects (≥ 100 MW) to begin operating between now & 2010
- 73 Coal (57,453 MW)
  - 8 IGCC Units
- 382 Natural Gas (254,530 MW)
- potentially 969 million tons CO_2 per year

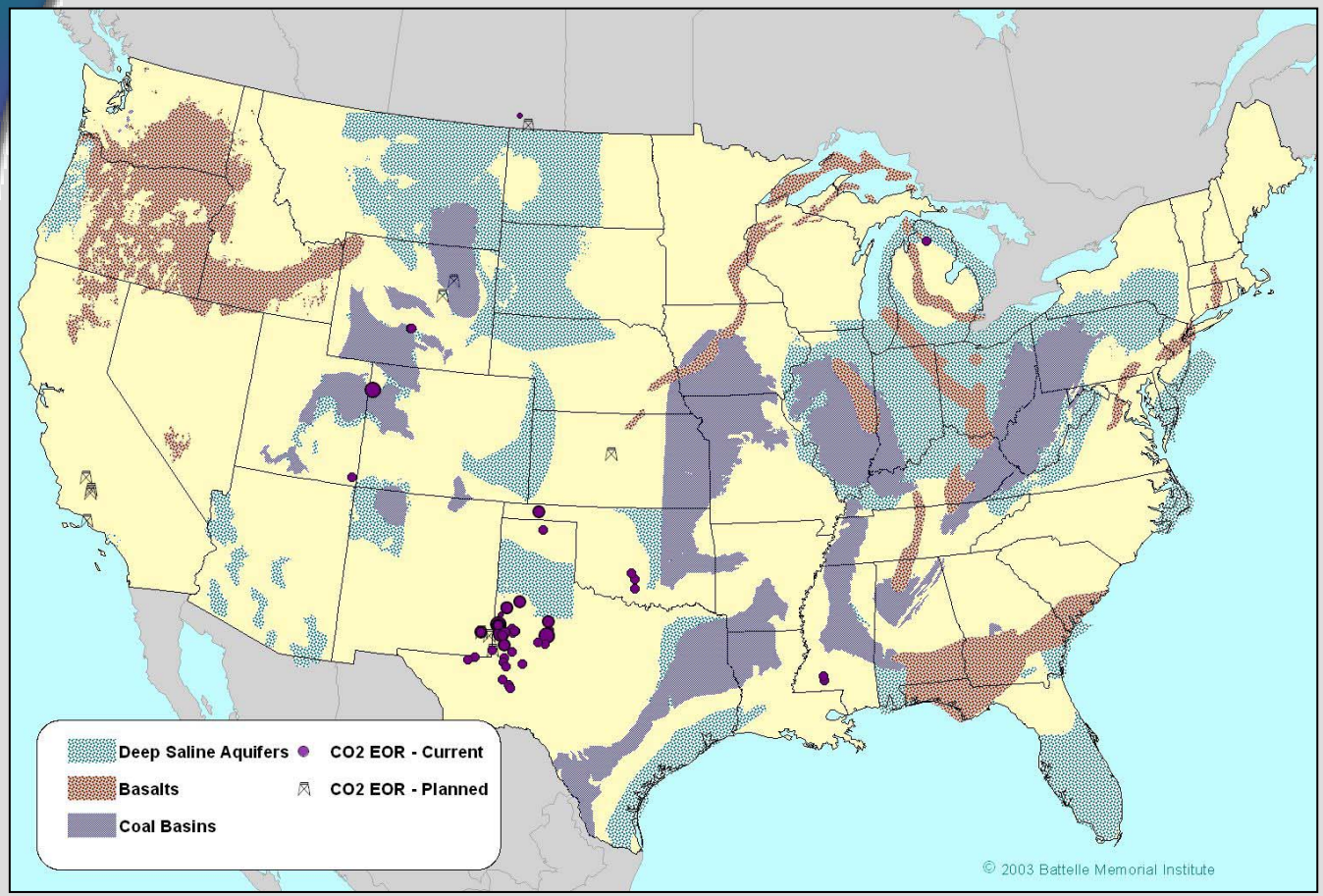
Plant Characteristics by Vintage Class

Vintage	#Units	Dominant Type	Avg. MW/Unit	CO_2 (tons) / MW	Avg. Capacity Factor
<1960	324	Coal	170	4,685	0.51
1960's	334	Coal	309	4,498	0.53
1970's	339	Coal	507	5,225	0.57
1980's	161	Coal	503	7,166	0.73
1990's	152	Gas	201	3,775	0.52
2000's	491	Gas	649*	3,069*	0.55*

** Values unreliable for comparison due to level of data available for planned plants*

- Large coal-fired units dominant through the 1980's
- Smaller gas-fired units become plant of choice over the 1990's (approx. 1992)
- Planned units mostly gas turbines, although coal plants to make a resurgence mid-decade

Battelle CO_2-GIS:
Geologic Sequestration Opportunities



Deep Saline Aquifers:
22 initial sedimentary formations and 5 basalt provinces

Deep Coal Basins:
21 basins, 230 TCF technically recoverable CBM reserves

Enhanced Oil Recovery (EOR): 70 Projects, 190,000 bbl/d enhanced production

Battelle CO_2-GIS:
Economic Screening Tool

- Customized tool developed to compare relative costs of capture and sequestration for plants and nearby sequestration pathways ($/ton CO_2)
- Economic Data
  - Capture (based on capture system, fuel, plant type, capacity factor, CO_2 emissions)
  - Transport (based on distance from source to sink, pipeline costs)
  - Disposal (varies depending on geologic reservoir type)
  - Credits (revenue from EOR/ECBM operations, carbon credits)

Economic Screening of Sequestration Opportunities

Vintage	Number (%) of Units within 50 miles of a CO2 Sequestration Reservoir	Total Amount (%) of CO2 Available (10^6 tons)	Predominant Lowest Cost Reservoir Option	Average Distance to Selected Reservoir (miles)	Weighted Average Costs for CO2 Capture, Transport & Sequestration ($/ton)
<1960	287 (89%)	238 (92%)	Coal Seams	11	22
1960's	283 (85%)	400 (86%)	Deep Saline Formations*	10	19
1970's	299 (88%)	832 (93%)	Coal Seams	12	12
1980's	138 (86%)	500 (86%)	Deep Saline Formations*	11	11
1990's	123 (81%)	91 (79%)	Deep Saline Formations	9	31
2000's	405 (83%)	786 (80%)	Deep Saline Formations*	11	25

** Includes Basalts*

- Deep saline formations offer the closest sequestration option for each of the plant categories
- Where value-added reservoirs (i.e., CBM or EOR) are accessible, these are often selected, even if it means building a longer pipeline

Characteristics by Vintage & Type

Vintage Class	Fuel	Total Capacity, MW	Avg. MW per Unit	Avg. Capacity Factor	CO_2 Emissions (10^6 tons per year)	Avg. Sequestration Costs ($/ton)
<1960	Coal	39,217	176	0.63	236	18
	Gas	13,255	154	0.26	20	64
	Oil	2,648	177	0.13	3	114
1960's	Coal	64,140	321	0.64	376	15
	Gas	31,707	294	0.34	65	43
	Oil	7,389	284	0.40	24	36
1970's	Coal	119,978	563	0.69	791	9
	Gas	36,381	383	0.39	76	34
	Oil	15,396	497	0.23	30	45
1980's	Coal	75,977	563	0.76	568	10
	Gas	4,156	181	0.62	11	45
	Oil	913	304	0.40	2	60
1990's	Coal	10,449	348	0.74	71	17
	Gas	19,507	165	0.48	43	54
	Oil	551	138	0.16	1	384
2000's	Coal	57,453	787*	N/A*	335	9*
	Gas	260,977	624*	N/A*	642	32*
	Oil	0	-	-	-	-

** unit data not available for all planned capacity*